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(56) Documents cited
GB 2000619 A US 4597067 A US 4390975 A
US 4293936 A

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UK CL (Edition K) E1F FHK
INT CL[5] E21B

(54) Acoustic telemetry

(57) A method for transmitting data from sensors (50) near the bottom of a well during drilling involves converting the signals from the sensors into binary digit form, and transmitting them as acoustic signals along the drill string (24) to a receiver (46) at the drilling rig. By using several hammers arranged to hit the drill string in succession, the data transmission rate is improved. The hammers may be arranged to hit one or more circumferential flanges on the drill string.

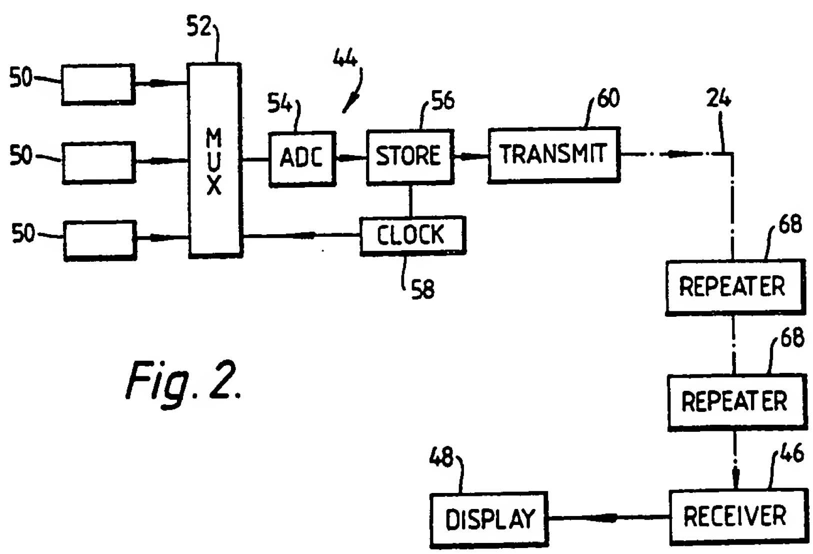

Fig. 2.

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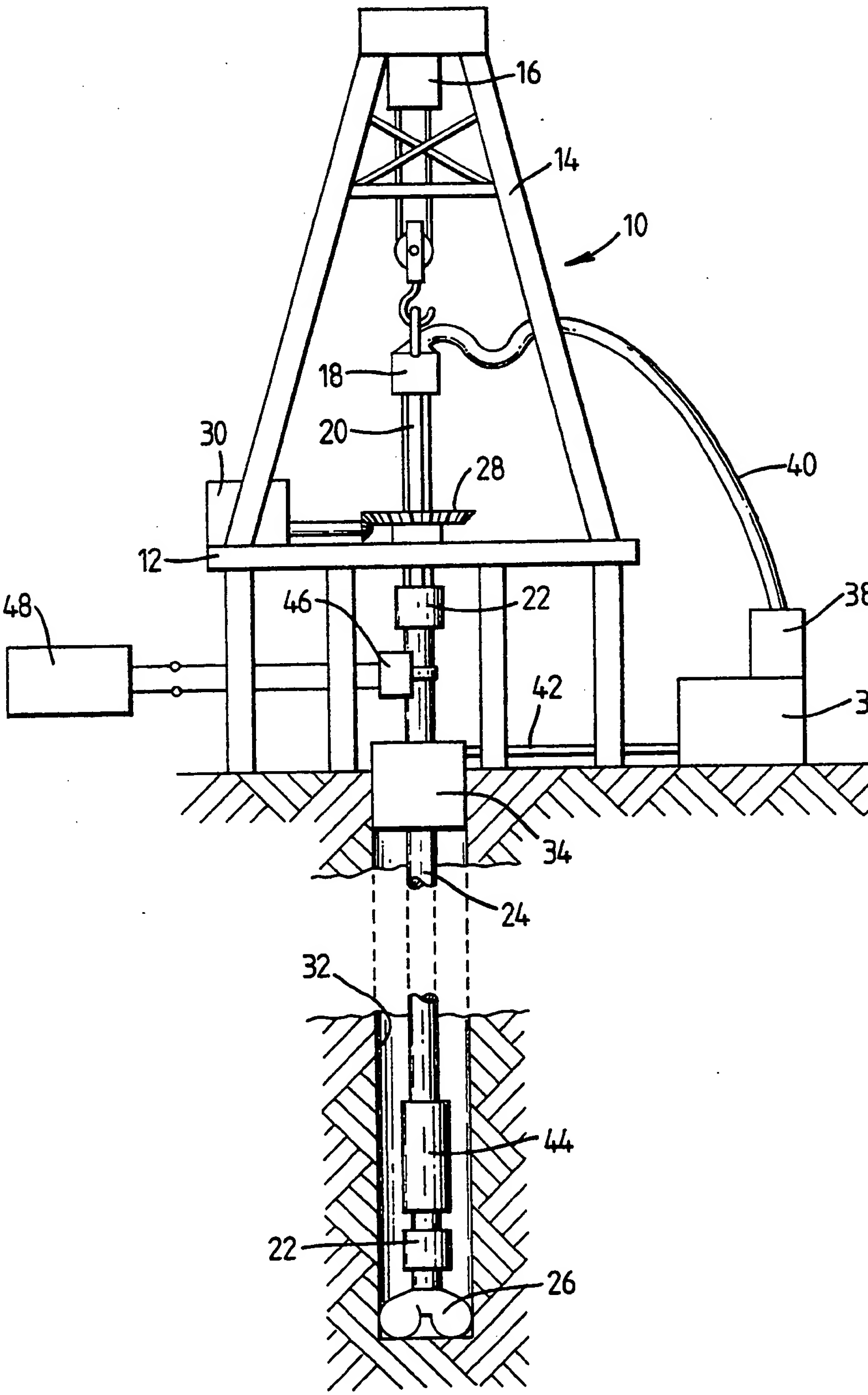
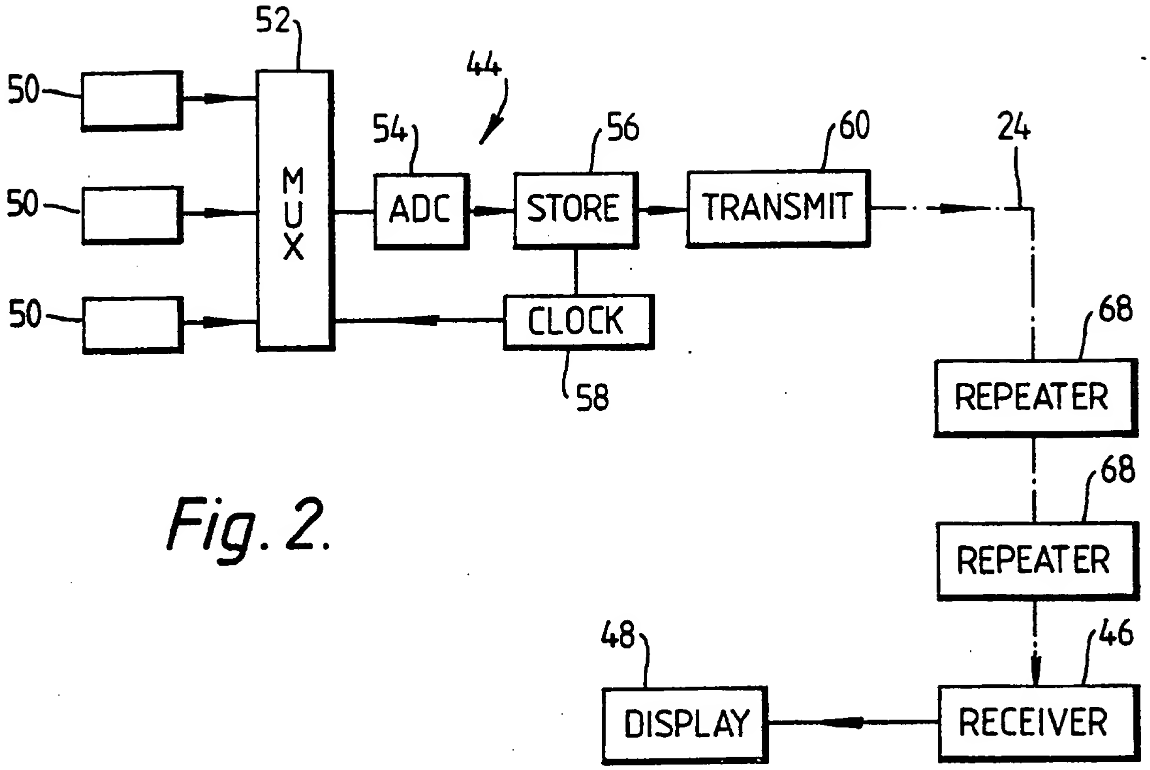
Fig.1.

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50
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MUX
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ADC
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STORE
60
TRANSMIT
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CLOCK
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REPEATER
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REPEATER
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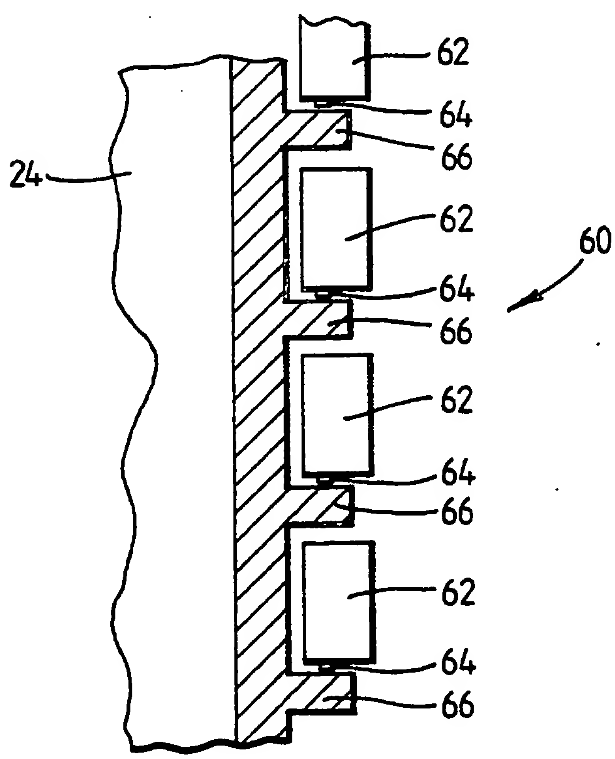
DISPLAY
46
RECEIVER

Fig. 2.

Fig. 3.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Acoustic Telemetry

This invention relates to an apparatus and a method for transmitting data from a sensor, particularly but not exclusively from a sensor within a borehole, such as an oil well, by an acoustic technique.

A number of parameters are routinely measured 'downhole' in oil wells during drilling operations by various sensors located a short distance behind the bit. The data thus generated can either be stored in downhole memory for later retrieval when the drill string is drawn out of the hole, or be encoded and transmitted to the surface via a suitable telemetry system.

The system currently used in the oil industry passes information as pressure waves in the drilling mud (Mud Pulse Telemetry). The mud is pumped down the inside of the drill string and returns to the surface via the annulus, serving to maintain hydrostatic pressure in the well, and to carry the drilling spoil back to the surface. Pressure waves are initiated in the mud column within the drill string either by checking or by easing the downward flow of the mud, producing positive or negative pulses respectively: the mud flow may be checked by a restrictor valve inside the drill string; the flow may be eased by opening a valve in the wall of the drill string, thereby providing the mud with a direct path to the annulus instead of forcing it past the bit. Such a system is discussed in US patent 4 520 468 (Scherbatskoy).

However, mud-based systems all exhibit severe data rate limitations, with typical transmission rates of about 1 baud or less. An item of survey data, for example relating to drilling direction, might be encoded as 15 bits and take about 30 seconds to transmit. As the variety and accuracy of the available downhole sensors increases,

the data rate limitations of the telemetry system will be seen increasingly to restrict the full and efficient use of Measurement-While-Drilling (MWD) survey systems.

It has also been proposed to transmit data using acoustic waves in the drill string. For example US patent 4 293 936 (Cox et al) describes tests carried out by Sun Oil Co. in 1948 in which means were provided to give a sharp hammer blow to an end of a drill pipe, the acoustic waves being detected by an accelerometer at the other end. Because of signal attenuation with such a broad band sound source, later work starting in 1968 by the same company developed the use of discrete frequencies, with repeater stations along the length of the pipe, data being transmitted digitally for example with 860 Hz representing a one and 880 Hz a zero. Cox et al also describe recent experimental measurements using impact from a hammer onto the drill pipe as a source of sound, and spectral analysis of the received signals at several different depths in a borehole. Signals were clearly detectable at a depth of over 1560 feet (475 m), but in some frequency bands there was much less attenuation than for other frequencies.

A data transmission system is described in US patent 4 390 975 (Shawhan) in which data is transmitted digitally, and in which repeaters are provided along the drill string which transmit at one of three different frequencies to ensure directionality. Ones and zeros are represented by transmitting and not-transmitting, respectively, a signal in a first part of a time interval, there being no signal transmission in the rest of the time interval. A similar system is described in US patent 3 790 930 (Lamel et al) in which signals are propagated by using torsional acoustic waves in the drill string; such waves are said to be non-dispersive, and to dissipate much less energy into the drilling fluid than longitudinal waves. The data may be encoded by a binary digital encoder. Yet another telemetry

system is described in SU 812 914 (Rukavitsin et al) in which data is transmitted in both directions along a drill string using acoustic waves of different types, such as longitudinal, transverse or torsional waves.

Thus there have been many proposals for telemetry using acoustic signals in drill strings, it being well known to convert the data into binary digital form; the acoustic signal may be generated by an impulsive blow (generating a wide frequency spectrum) or by a discrete frequency generator; and a variety of wave types have been proposed. However none of these telemetry techniques appears to have been widely adopted in industry.

According to the present invention there is provided an apparatus for telemetry along a pipe in a borehole, the apparatus incorporating at least one sensor arranged to generate an electrical signal representing a measured quantity, means to convert the electrical signal into a binary digital form, and a plurality of hammer means arranged to be actuated successively to transmit successive binary digits by impacting with the pipe.

Preferably each hammer means is arranged when actuated to deliver an impact to the pipe in one of two opposite directions, an impact in one direction representing the digit one and an impact in the opposite direction representing the digit zero.

The use of discrete frequencies to transmit data in a drill-pipe, as proposed in the prior art, has a problem in that the transmission characteristics of a drill-pipe are complex, typically consisting of frequency bands, "pass bands" of width about 100 Hz in which signals can be transmitted well, alternating with bands in which signals are attenuated strongly; within a pass band are several frequencies which are transmitted well, alternating with

frequencies which are strongly attenuated (see "Acoustical properties of drill strings" by D.S. Drumheller, J. Acoust. Soc. Am., 85(3), March 1989). The frequencies which are transmitted well depend upon the lengths of pipe sections, on the nature of the inter-pipe joints, and on the overall length of the drill string, so that it is difficult to choose suitable discrete frequencies for data transmission.

By using hammer means to deliver impacts the generated acoustic signal is broad band, so that one can be certain a signal will propagate. The use of a plurality of hammer means, which are actuated successively, enables faster data encoding than a single hammer as the inertia of the hammer is not a limiting factor. Furthermore the use of impacts in opposite directions to represent the different digits renders the technique less subject to interference from other sources of noise.

Desirably the number of hammer means is between four and twenty, preferably between four and ten, inclusive. The preferred wave type is longitudinal, but torsional waves are also suitable; to generate longitudinal waves the hammer means desirably is caused to move parallel to the longitudinal axis of the pipe prior to impact, and to impact with a surface transverse to the axis. The surface with which it impacts may be provided by a recess in the wall of the pipe or by a circumferential flange or partial flange on the inside or outside of the pipe.

For data telemetry over long distances it may be necessary to provide repeaters, to receive the data signals and re-transmit them. The repeater may incorporate a memory to record a complete data string, and means to transmit the complete data string after it has all been received; each data string may incorporate data indicating its beginning and end, and/or identifying that data string.

The repeater may incorporate means responsive to the identifying data or to the beginning indicator to prevent it recording and re-transmitting signals propagating in the wrong direction along the pipe. Alternatively it may incorporate means for sensing the direction of propagation of signals, so as to discriminate between signals travelling in the right and wrong directions (i.e. signals received by a repeater from adjacent repeaters below and above it), these sensing means comprising a pair of acoustic wave sensors spaced apart along the pipe and means for sensing at which sensor the signal is received first.

The invention also provides a method of telemetry along a pipe in a borehole the method comprising sensing a quantity to be measured and generating an electrical signal representative thereof, converting the signal into a binary digital form, and transmitting successive digits acoustically along the pipe by actuating successively a plurality of hammer means.

The invention will now be further described by way of example only and with reference to the accompanying drawings, in which:

Figure 1 shows a diagrammatic side view of an oil well drilling rig incorporating a telemetry apparatus;

Figure 2 represents by a block diagram the operation of the telemetry apparatus of Figure 1; and

Figure 3 shows in greater detail a part of the telemetry apparatus of Figure 1.

Referring to Figure 1 there is shown a drilling rig 10 incorporating an acoustic telemety system. The rig 10 is of conventional type, incorporating a platform 12 on which

is a derrick 14 supporting a hoist 16. The hoist 16 supports a swivel 18 which is rotatably connected to a polygonal kelly 20. The kelly 20 is connected by a unit 22 to a drill string 24, to the lower end of which is connected a drill bit 26 by a second unit 22. Each unit 22 incorporates means for acoustically isolating the drill string 24, from the drill bit 26 and from the kelly 20; this may be as described in US patent 4 066 995 (Matthews). The entire drill string 24 and the bit 26 can be rotated continuously by rotation of a rotary table 28, as the kelly 20 slides in a corresponding aperture in the table 28, and the table 28 is turned by a motor 30. At the top of the well 32 is a blow-out preventer 34. Drilling mud from a reservoir 36 is supplied by a pump 38 through a pipe 40 to the swivel 18. It flows down through the kelly 20 and the drill string 24, and returns to the surface in the well bore 32 outside the drill string 24, then through the blow-out preventer 34 and back via a pipe 42 to the reservoir 36.

Incorporated in the drill string 24 near the bit 26 but above the isolating unit 22 is a sensor and transmitter unit 44. This contains sensors for parameters such as pressure and temperature, and for orientation of the drill string 24, amongst others, and contains means for representing the values of those parameters as acoustic signals in the drill string 24, as described later. Clamped onto the outside of the drill string 24 above the blowout preventor 34 and just below the top isolating unit 22 is an acoustic signal receiver 46, connected electrically to a data storage and display unit 48.

Referring now to Figure 2, the unit 44 incorporates a plurality of sensors 50 (only three are shown) which provide electrical signals representing the values of the measured parameters. These signals are provided in succession by a multiplexer 52 to an analogue-to-digital

converter 54; the binary digits representing the parameters are then stored by a store 56. Operation of the circuit is controlled by a clock 58 so that at intervals a transmitter 60 is energised to generate digital signals in the drill string 24 representing all the values in the store 56. The data is thus represented as a sequence of ones and zeros. Successive digits are transmitted every twentieth of a second, being represented by the presence or absence of a longitudinal wave sound impulse in each twentieth of a second period. As shown in Figure 3 the transmitter 60 comprises four electromagnets 62 each with a spring-loaded armature 64, arranged adjacent to four circumferential flanges 66 around a portion of the drill string 24. If an electromagnet 62 is energised its armature 64 strikes the adjacent flange 66 a sharp blow and then rebounds to its original position. A pulse of acoustic waves of frequencies up to about 1 kHz is generated in the drill string 24 and propagates along it. Successive digits are transmitted by the different electromagnets 62 in sequence. Thus although digits are sent at the rate of twenty a second, each electromagnet 62 is only liable to be energised every fifth of a second.

Referring again to Figure 2, the receiver 46 includes a piezoelectric accelerometer acoustically coupled to the drill string 24, and which consequently receives signals corresponding to the sequence of binary digits. These are interpreted and displayed by the unit 48. Where the drill string 24 is too long for satisfactory signal reception, then repeaters 68 may be provided at intervals along its length, for example every half kilometre. Each repeater 68 comprises two accelerometers coupled to the drill string 24 about 300 mm apart, and a discrimination circuit which accepts only those signals received by the lower accelerometer first; a store to memorize the complete sequence of binary digits corresponding to the accepted signals; and a transmitter identical to the transmitter 60

in the unit 44. Only after receipt of the entire sequence of digits is the sequence transmitted by the repeater 68.

It will be appreciated that the telemetry system of the invention may differ in some repects from that described above. For example instead of arranging each electromagnet 62 to hit a different flange 66, instead all four electromagnets 62 might be arranged to hit the same flange 66, being spaced around it. Indeed there might be a larger number of electromagnets 62, for example twelve, arranged in three sets of four to hit three different flanges 66. Furthermore the time intervals between successive activations of one electromagnet 62 might differ from the value of a fifth of a second given above. In a further modification each electromagnet is placed between two flanges 66 and can be energised so as to hit one flange or the other, so indicating the digits zero or one respectively.

In this case it is preferable for the receiver 46 to incorporate pattern recognition circuitry to distinguish the received wave patterns corresponding to these two different impacts, which differ in phase. The system may also incorporate a sensor to detect if there is significant noise in the drill string 24 due to operation of the drill bit 26, and to ensure that data is only transmitted at times when there is little noise, for example when drilling is stopped in order that an additional pipe length can be added to the drill string 24.

Claims

1. An apparatus for telemetry along a pipe in a borehole, the apparatus incorporating at least one sensor arranged to generate an electrical signal representing a measured quantity, means to convert the electrical signal into a binary digital form, and a plurality of hammer means arranged to be actuated successively to transmit successive binary digits by impacting with the pipe.

2. An apparatus as claimed in Claim 1 wherein each hammer means is arranged when actuated to deliver an impact to the pipe in one of two opposite directions, an impact in one direction representing the digit one and an impact in the opposite direction representing the digit zero.

3. An apparatus for telemetry along a pipe in a borehole substantially as hereinbefore described with reference to, and as shown in, the accompanying drawings.

4. A method a method of telemetry along a pipe in a borehole the method comprising sensing a quantity to be measured and generating an electrical signal representative thereof, converting the signal into a binary digital form, and transmitting successive digits acoustically along the pipe by actuating successively a plurality of hammer means.

5. A method of telemetry along a pipe in a borehole substantially as hereinbefore described with reference to, and as shown in, the accompanying drawings.

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